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(54) MANAGEMENT OF VIRTUAL MACHINE HEALTH USING DUAL DATABASES

(71) Applicant: **International Business Machines Corporation**, Armonk, NY (US)

(72) Inventors: **Veena Ganti**, Austin, TX (US); **Rui Yang**, Austin, TX (US); **Lakshmi Yadlapati**, Austin, TX (US); **James Pafumi**, Leander, TX (US)

(73) Assignee: **INTERNATIONAL BUSINESS MACHINES CORPORATION**, Armonk, NY (US)

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G06F 9/455	(2018.01)
G06F 11/20	(2006.01)
G06F 16/23	(2019.01)

(52) **U.S. Cl.**
CPC ***G06F 9/45558*** (2013.01); ***G06F 11/2094*** (2013.01); ***G06F 16/2379*** (2019.01); *G06F 2009/45579* (2013.01); *G06F 2009/45591* (2013.01); *G06F 2201/82* (2013.01)

(58) **Field of Classification Search**
CPC G06F 9/45558; G06F 11/2094; G06F 16/2379
See application file for complete search history.

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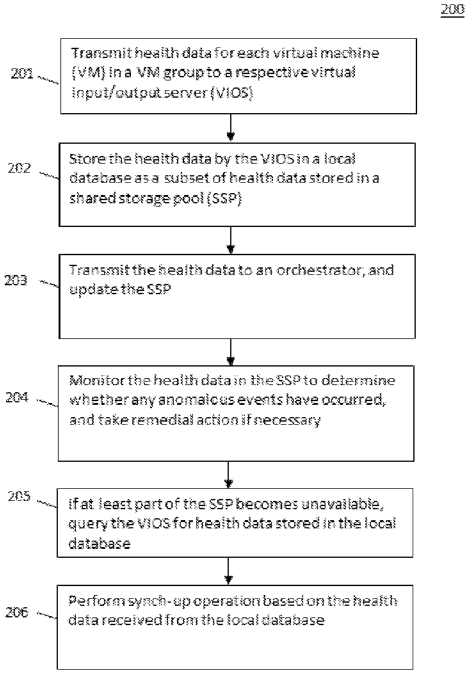
Primary Examiner — Joshua P Lottich
(74) *Attorney, Agent, or Firm* — Cantor Colburn LLP; David Quinn

(57) ABSTRACT

A system includes a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP). Each VIOS is associated with a respective group of VMs of the plurality of VMs and is configured to receive health data for each VM of the respective group of VMs. The system also includes a health information database associated with each VIOS of the plurality of VIOSs, the health information database configured to store a subset of the health data for each VM of the respective group of VMs. Each VIOS is configured to transmit the health data for each VM of the respective group of VM to the SSP, and in parallel, store the subset of the health data in the health information database.

20 Claims, 3 Drawing Sheets


200
201
Transmit health data for each virtual machine (VM) in a VM group to a respective virtual input/output server (VIOS)
202
Store the health data by the VIOS in a local database as a subset of health data stored in a shared storage pool (SSP)
203
Transmit the health data to an orchestrator, and update the SSP
204
Monitor the health data in the SSP to determine whether any anomalous events have occurred, and take remedial action if necessary
205
If at least part of the SSP becomes unavailable, query the VIOS for health data stored in the local database
206
Perform synch-up operation based on the health data received from the local database

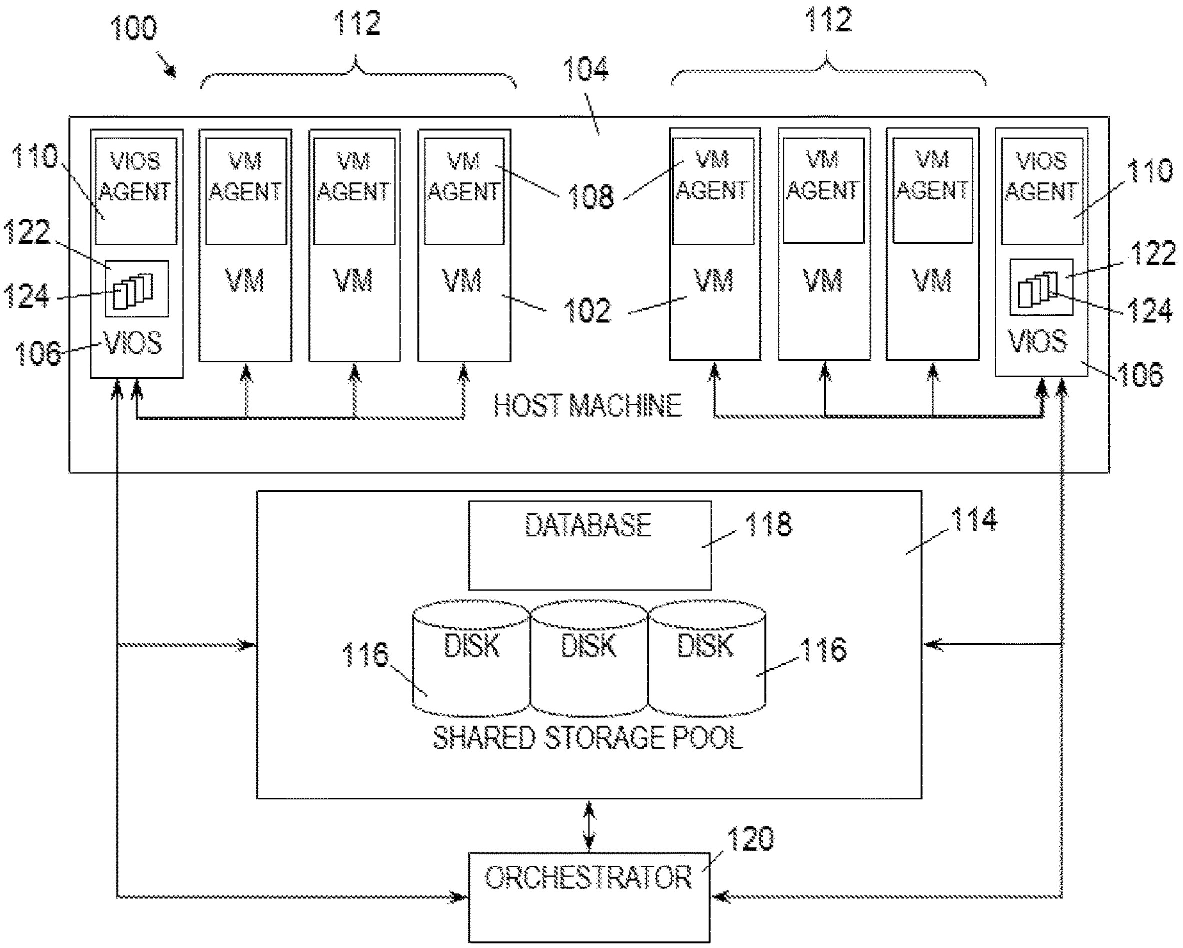
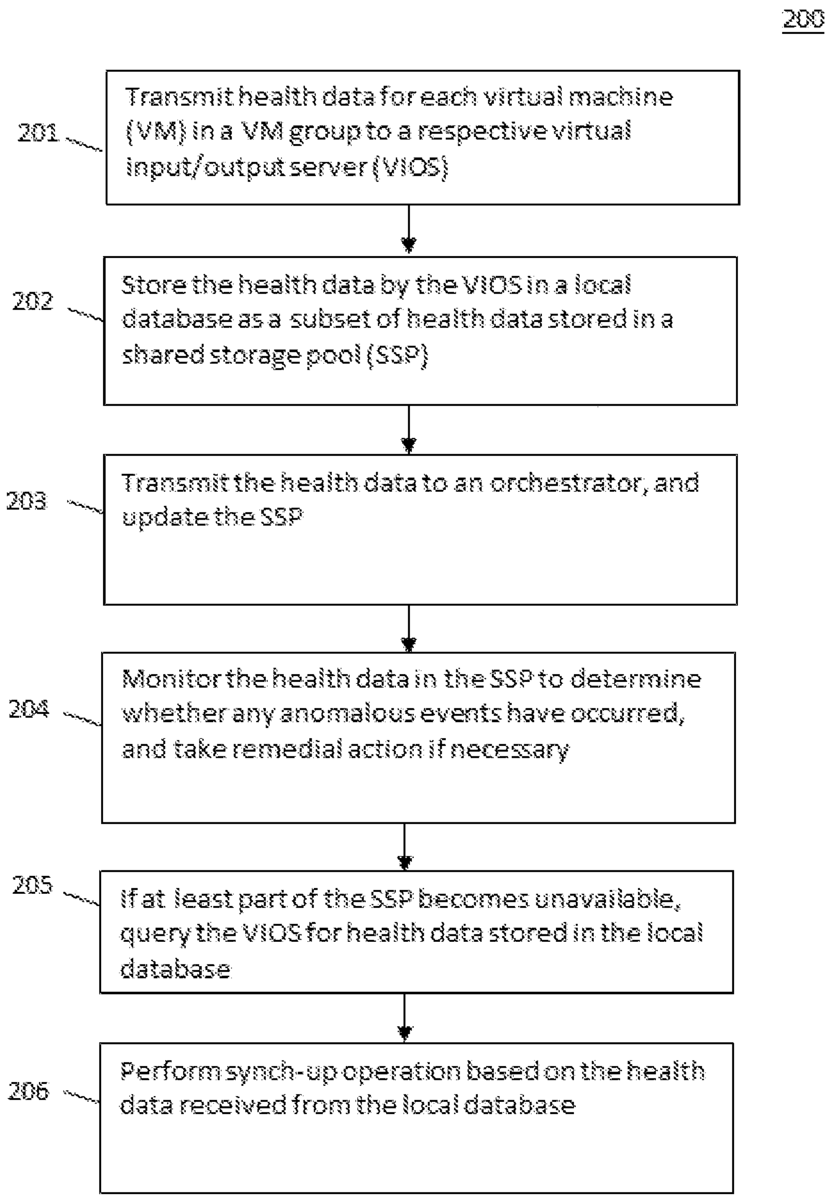

100
112
112
104
110
VIOS AGENT
VM AGENT
VM AGENT
VM AGENT
108
VM AGENT
VM AGENT
VM AGENT
VIOS AGENT
110
122
124
VM
VM
VM
102
VM
VM
VM
122
124
106
VIOS
VIOS
106
HOST MACHINE
DATABASE
118
114
116
DISK
DISK
DISK
116
SHARED STORAGE POOL
120
ORCHESTRATOR

FIG. 1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Store the health data by the VIOS in a local database as a subset of health data stored in a shared storage pool (SSP)
203
Transmit the health data to an orchestrator, and update the SSP
204
Monitor the health data in the SSP to determine whether any anomalous events have occurred, and take remedial action if necessary
205
If at least part of the SSP becomes unavailable, query the VIOS for health data stored in the local database
206
Perform synch-up operation based on the health data received from the local database

FIG. 2

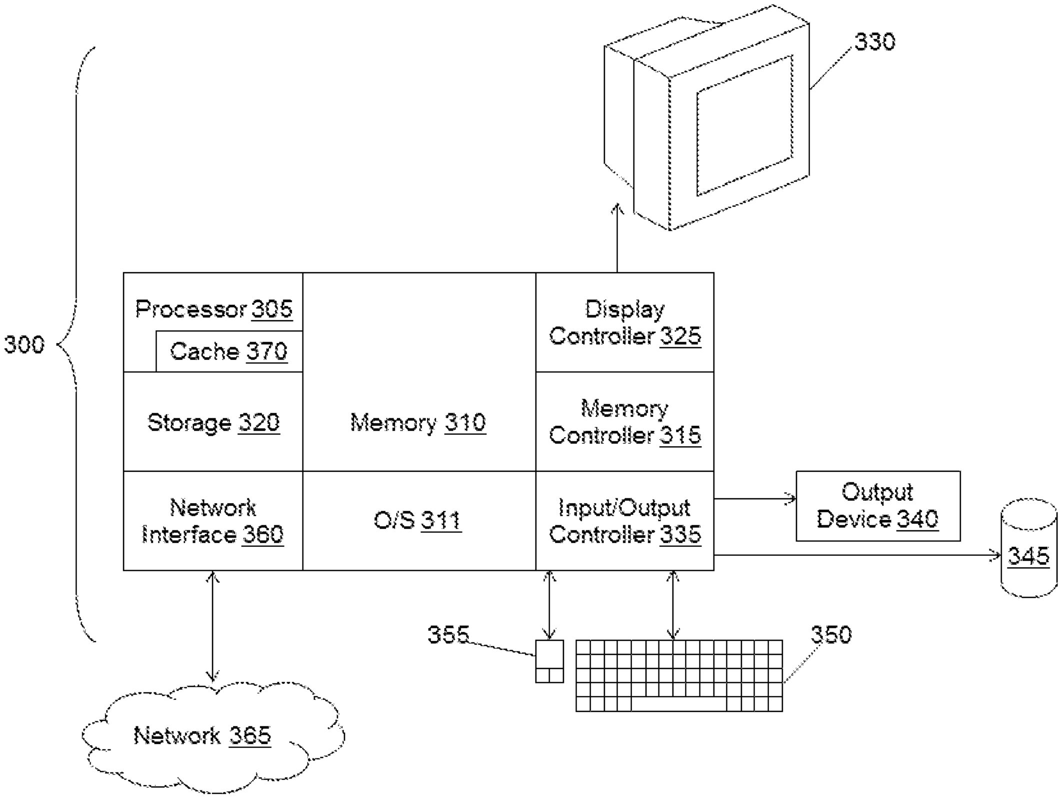
330
300
Processor 305
Cache 370
Memory 310
Display Controller 325
Storage 320
Memory Controller 315
Network Interface 360
O/S 311
Input/Output Controller 335
Output Device 340
345
355
350
Network 365

FIG. 3

MANAGEMENT OF VIRTUAL MACHINE HEALTH USING DUAL DATABASES

BACKGROUND

The present invention relates to virtual machines and, more specifically, to using multiple databases to manage the health of virtual machines.

A virtual machine (VM) is an emulation of a computer system, and generally multiple VMs can run on a host machine, such as a server. The host machine uses a hypervisor to manage the virtual machines, each of which may be a logical partition of the host machine. A virtual input/output server (VIOS), which is a specialized logical partition, manages physical input resources and output resources among VMs with which the VIOS is connected.

One or more VIOSs can participate in a shared storage pool (SSP). The SSP is a pool of storage area network (SAN) storage devices that can be used among the VIOSs and is useful in improving the use of available storage, simplifying administrative tasks and simplifying the aggregation of storage devices for use by VMs.

SUMMARY

According to one embodiment, a system includes a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP). Each VIOS is associated with a respective group of VMs of the plurality of VMs and is configured to receive health data for each VM of the respective group of VMs. The system also includes a health information database associated with each VIOS of the plurality of VIOSs, the health information database configured to store a subset of the health data for each VM of the respective group of VMs. Each VIOS is configured to transmit the health data for each VM of the respective group of VM to the SSP, and in parallel, store the subset of the health data in the health information database.

According to one embodiment, a method of managing a shared storage environment includes monitoring the shared storage environment, the shared storage environment including a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP), where each VIOS is associated with a respective group of VMs of the plurality of VMs. The method also includes receiving health data for each VM of the respective group of VMs, transmitting the health data for each VM of the respective group of VM to the SSP, and in parallel, storing a subset of the health data for each VM of the respective group of VMs in a health information database, the health information database associated with each VIOS of the plurality of VIOSs.

According to one embodiment, a computer program product includes a computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processing system to perform a method that includes monitoring a shared storage environment. The shared storage environment includes a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP), where each VIOS is associated with a respective group of VMs of the plurality of VMs. The method also includes receiving health data for each VM of the respective group of VMs, transmitting the health data for each VM of the respective group of VM to the SSP, and in parallel, storing a subset of the health data for each VM of the respective group of VMs in a health information database, the health information database associated with each VIOS of the plurality of VIOSs.

Additional technical features and benefits are realized through the techniques of the present invention. Embodiments and aspects of the invention are described in detail herein and are considered a part of the claimed subject matter. For a better understanding, refer to the detailed description and to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The specifics of the exclusive rights described herein are particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features and advantages of the embodiments of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** depicts a shared storage computing system according to one or more embodiments of the present invention;

FIG. **2** is a flow diagram of a method of managing health information in a shared storage computing system, according to one or more embodiments of the present invention; and

FIG. **3** is a diagram of a computer system for implementing some or all aspects of one or more embodiments of the present invention.

DETAILED DESCRIPTION

Systems, methods and computer program products are provided for monitoring and recovering health information in a computing system having shared storage. An embodiment of the computing system includes one or more groups of virtual machines (VMs). Each group of VMs is managed by a virtual input/output server (VIOS) and is connected to a shared storage pool (SSP) that stores data and information including health information for each VM. An orchestration node is connected to the SSP and manages the collection of health information for each VM and the storage of the health information in the SSP.

In one embodiment, each VIOS includes or otherwise has access to a supplemental database. The supplemental database associated with a VIOS allows for storing health information associated with each VM in the VM group managed by the VIOS. The supplemental database may be a local database that resides in each VIOS. The supplemental database for a given VIOS stores all or a portion of the health data that is transmitted by the given VIOS to the SSP, and the health data stored in the supplemental database can be accessed by the orchestration node by querying the given VIOS. The stored health data may be stored in a table and/or in a copy of a portion of a catalog maintained in the SSP.

Embodiments described herein provide a number of advantages and technical effects. For example, the embodiments provide a quick and efficient way to recover health information stored in the SSP in the event that all or part of the SSP fails, or that at least part of the health information in the SSP becomes unavailable. The embodiments ensure that the orchestration node is continuously aware of the health of each VM and allow the orchestration node to make informed policy decisions in the event of a failure. The embodiments also provide a method to quickly recover and/or synch-up the VMs by utilizing the supplemental database associated with each VIOS.

FIG. **1** shows an embodiment of a shared storage computing system **100**, which includes a plurality of VMs **102**. Each VM **102** may be a logical partition (LPAR) or another form of a virtual machine. The various VMs **102** may run on one or more host machines. For example, the VMs **102** are shown as running on a server **104**. It is noted that the system **100** may include multiple servers **104** or other host machines.

The system **100** also includes a plurality of VIOSs **106**, also referred to as VIOS partitions. A VIOS is a specialized logical partition that manages I/O resources for one or more VMs **102** running on the same server **104** or other host machine. Each VIOS **106** can be considered a VIOS node and each VM **102** can be considered a VM node.

In some embodiments, each VM **102** includes a VM agent **108**, and each VIOS **106** includes a VIOS agent **110**. In some embodiments of the invention, a VM agent **108** is a daemon running in a respective VM **102**, and a VIOS agent **110** is a daemon running in a respective VIOS **106**. Alternatively, a VM agent **108** may be incorporated into the code of the VM **102**, and a VIOS agent **110** may be incorporated into the code of the VIOS **106**. Generally, each VM agent **108** may be in communication with the VIOS agent **110** of its associated VIOS **106**, which manages the I/O resources for that VM **102**. Each VIOS agent **110** may be able to communicate with respective VM agents **108** through an API for VIOS-VM communications. Generally, activities described herein as being performed by a VIOS **106** may be performed by the respective VIOS agent **110**, and activities described herein as being performed by a VM **102** may be performed by the respective VM agent **108**.

In one embodiment, each VIOS **106** is assigned to monitor the health of a respective group of VMs **102**, which is referred to herein as a VM group **112**. For a given VM group **112**, the VIOS **106** assigned to the VM group **112** queries the health of each VM **102** in the VM group **112** by retrieving health information for each VM **102**. The health information is stored in a shared storage system such as a shared storage pool (SSP) **114**.

In one embodiment, the SSP **114** is a global distributed database that is accessible by all of the VIOSs **106** in the system **100**, and includes various storage devices that are usable by the various VIOSs **106**. For example, the SSP **114** includes one or more disks **116** or portions thereof, and a database **118**, referred to as an SSP database **118**. The SSP database **118** may be used for various purposes, such as those related to management of allocation of the disks **116**. The SSP database **118** may be stored on one or more of the disks **116**. For example, the SSP database **118** may be redundantly stored on each disk **116** or distributed across the disks **116**. The SSP database **118** may be a relational database or various other storage objects capable of maintaining data as described herein, and is not limited to the configuration shown in FIG. **1**.

The system also includes a specialized node, referred to herein as an orchestration node or orchestrator **120**, that manages the collection of health information from the VMs **102**, and the storage of such information in the SSP **114**. The orchestrator **120** may also be responsible for some or all aspects of disaster recovery.

The orchestrator **120** communicates with the SSP **114** as needed to store or access health information. The orchestrator **120** may reside on the server **104** or other device in the system, e.g., as a VIOS. In some embodiments, the orchestrator **120** is remote from the SSP **114**. For example, the orchestrator **120** may be incorporated into a management system on a remote server. The orchestrator **120** may be hardware, software, or a combination of both.

Each VIOS **106** collects health information from all of the VMs **102** in the respective VM group **112** that is assigned to the VIOS **106**. For example, each VM agent **108** communicates health data for a respective VM **102** to an associated VIOS **106** describing the health of the respective VM **102**, and the VIOS agent **110** receives this health data.

The health information may be a variety of types of health data. For example, the health data can include a periodic indicator referred to as a "heartbeat," which indicates that an associated VM **102** is running. Other examples of health data include an indication as to which applications are running on an associated VM **102**, and a heartbeat for each application that is currently running on an associated VM **102**. Each VM **102** may communicate this health data to an associated VIOS **106** according to a predetermined schedule. For example, and not by way of limitation, the health data may be communicated periodically at established intervals (e.g., every two seconds), or the health data may be continuously communicated in a data stream. It will be understood that various schedules may be used for the communication of this health data.

Each VIOS **106** receives health data from the VMs **102** in its respective VM group **112**, and transmits or otherwise communicates the health data to the orchestrator **110**. Each VIOS **106** may communicate the health data of its VMs **102** to the orchestrator **120** according to a predetermined schedule, which may be based on the schedule by which the health data is reserved from the VMs **102**. For example, a VIOS agent **110** may transmit the health data of its associated VMs **102** to the orchestrator **120** periodically at established intervals, or that health data may be continuously communicated in a data stream. It will be understood that various schedules may be used for the communication of this health data.

In some embodiments, the health data in the SSP **114** (e.g., in the SSP database **118**) is updated dynamically as the health of the VMs **102** changes. The health data may be updated in real time or near real time. For example, if a VM **102** transmits health data that would result in an update to the health data stored in the SSP database **118**, the associated VIOS **106** detects the health data and transmits the health data in real time to the orchestrator **120**, which updates the database **118** to incorporate the health data.

As noted above, the orchestrator **120** can access health information from any VIOS **106** regarding the VMs **102** associated therewith, and use the health data to make disaster recovery policy decisions. In some instances, the SSP database **118** and/or other components of the SSP **114** can become a single point of failure if the SSP **114** or components thereof go down or fail. Reasons for failure may include, e.g., pool disk problems, software problems (e.g., problems with Reliable Scalable Cluster Technology (RSCT), the pool file system becoming full, etc.). In such scenarios, the orchestrator **120** has no information regarding the health of the VMs **102** and thus can make incorrect disaster recovery decisions, as the orchestrator is not aware of updates to the health of the VMs **102**.

In some embodiments, the system **100** includes one or more supplemental databases **122** for redundantly storing health information that is stored in the SSP **114** for each of the VMs **102** monitored by a VIOS **106**. The one or more supplemental databases **122** are also referred to herein as one or more health information databases **122** or VIOS databases **122**. A VIOS database **122** is provided for each

VIOS **106** in the system **100** and is remote from the SSP **114**, so that failures in the SSP **114** do not affect the health information stored in the VIOS database **122**.

These embodiments address the challenges presented by conventional SSP systems, by permitting the recovery of health information in the event that health information in the SSP **114** becomes unavailable. Health information may become unavailable for a number of reasons, such as damage to or failure of the SSP **114** or components thereof, loss of data, etc. In such an event, the orchestrator **120** can retrieve health information from some or all of the VMs **102** and reconstruct the health information as needed.

In one embodiment, each VIOS database **122** is a local database that resides in a respective VIOS **106**. The VIOS database **122** can be managed by, for example, a VIOS agent **110**, to request and receive health information from each VM **102** in the VM group **112** associated with the respective VIOS **106**. The VIOS agent **110** may also be used to communicate with the orchestrator **120** to facilitate the transfer of health information to the orchestrator **120**. Although the VIOS databases **122** are shown as residing in respective VIOSs **106**, they are not so limited and can be in any suitable location, such as in a cache residing on the host machine **104** or on a separate device.

Health information may be stored in a VIOS database **122** as a subset of the health data that is stored in the SSP **114**. For example, when a VIOS **106** receives health data for a VM **102**, the health data for that VM **102** is transmitted to the orchestrator **120**, and a copy of the health data for that VM **102** is in one or more tables **124**. The copy of the health data can be stored as any suitable data structure and is thus not limited to one or more tables **124**. For example, the copy of the health data may be stored in a database catalog of the database **118**, and the health data is stored in a portion of the catalog that resides in the VIOS **106**.

When there is an update in the health data for a given VM **102**, the VIOS **106** managing the given VM **102** updates the appropriate data in the SSP **114** and, in parallel (e.g., simultaneously), updates the copy of the health data in an associated VIOS database **122**. In one embodiment, when a VIOS **106** updates data in the SSP **114** for a VM **102**, the VIOS **106** also updates one or more entries in table **124** associated with the VM **102**. For example,

FIG. **2** illustrates an embodiment of a method **200** of managing health information in a shared storage computing system. The method **200** may be performed by a processor, OS or other suitable application or program. Although the method **200** is discussed in conjunction with the system **100**, the method **200** is not so limited. The method **200** is discussed in conjunction with blocks **201-206**. The method **200** is not limited to the number or order of steps therein, as some steps represented by blocks **201-206** may be performed in a different order than that described below, or fewer than all of the steps may be performed.

At block **201**, each VM **102** transmits health data to a respective VIOS **106**. Transmission of the health data to the VIOS **106** may occur periodically or as needed. For example, each VM **102** periodically reports an indication (e.g., a "heartbeat") as to whether the VM **102** is running properly, and/or reports an indication as to which applications in the VM **102** are currently running.

At block **202**, the VIOS **106** stores the received health data in its respective VIOS database **122**, which in one embodiment is a local database residing in the VIOS **106**. For example, when the VIOS **106** receives health data, appropriate entries in table **124** in the respective database **122** are updated or created. The received health data is stored in the respective database **122** a subset of the health data stored in the SSP **114**.

At block **203**, the VIOS **106** transmits the health data of its associated VMs **120** to the orchestrator **110**, and the orchestrator **110** updates the SSP database **118** with the transmitted health data.

At block **204**, the orchestrator **110** monitors the health data in the SSP **114** to determine whether any of the VMs **102** are operating outside expected parameters and/or whether any anomalous events occur (e.g., the SSP **114** fails). If necessary, the orchestrator **110** can take remedial action.

For example, the orchestrator **110** may have access to a set of established policies that set operating parameters (e.g., thresholds) for the health data. The orchestrator **110** may compare the health data of each VM **102** to these policies to determine whether the health data falls within expected operating parameters. If a VM's health data falls outside the expected operating parameters, then the orchestrator **110** may deem the VM **120** to be operating anomalously. As a result, the orchestrator **110** may initiate a remedial action. Remedial actions include, for example, querying the VM **102** or its associated VIOS **106** for additional health information, allocating additional resources to the VM **102**, restarting one or more applications on the VM **102**, restarting the VM **102**, restarting an application on a different VM **102**, taking the VM **102** offline, and/or notifying an administrator of a detected anomaly.

At block **205**, if all or a part of the SSP **114** fails or health data in the SSP **114** is otherwise unavailable, the orchestrator **120** queries one or more VIOSs **106** and retrieves the health data for one or more VMs. Upon receipt of such a query, a VIOS **106** will retrieve health data stored in its respective VIOS database **122** and transmit the retrieved data to the orchestrator **120**.

In one embodiment, the orchestrator **120** queries each of the VIOSs **106** for the health data associated with each of the VMs **102** that the VIOS **106** manages. The orchestrator **120** may consolidate the health data from some or all of the VMs **102** to reconstruct all or part of the health data that was previously stored in SSP **114**, or to otherwise get a consolidated view of the health of the system **100**. It is noted that in some cases, the health status of one or more VMs **102** changes after the SSP **114** failure. In such cases, reconstructing the health data does not result in an identical set of data. Instead, where appropriate, the reconstructed health data is updated data that reflects the current state of all or some of the VMs **102**.

This fault tolerant approach of using dual databases (e.g., the SSP database **118** and the various VIOS databases **122**) to get health information ensures that the orchestrator **120** has a view of VM health at all times to make an informed policy decision. Once the SSP database **118** is back online, the orchestrator **120** can use the VIOS databases **122** to quickly recover and perform appropriate synch-up operations.

AT block **206**, when the SSP **114** comes back online or otherwise becomes available, the orchestrator **120** may perform a synch-up operation. The synch-up operation includes gathering health data from all of the VIOSs **106** and updating the SSP database **118** accordingly. This allows for a relatively quick sync-up, in that the health data can be quickly recovered and synchronized without having to individually query each VM **102**.

FIG. **3** is a diagram of a computer system **300** for implementing some or all aspects of the system **100**, according to some embodiments of this invention. The systems and methods described herein may be implemented in hardware, software (e.g., firmware), or a combination thereof. In some embodiments, the methods described may be implemented, at least in part, in hardware and may be part of the microprocessor of a special or general-purpose computer system **300**, such as a personal computer, workstation, minicomputer, or mainframe computer. For example, and not by way of limitation, the orchestrator **120** may be implemented as one or more computer systems **300** or portions thereof, and each of the VIOSs **106** and the VMs **102** may run on one or more computer systems **300** or portions thereof.

In some embodiments, as shown in FIG. **3**, the computer system **300** includes a processor **305**, a memory **310** coupled to a memory controller **315**, and one or more input devices **345** and/or output devices **340**, such as peripherals, that are communicatively coupled via a local I/O controller **335**. These devices **340** and **345** may include, for example, a printer, a scanner, a microphone, and the like. Input devices such as a conventional keyboard **350** and mouse **355** may be coupled to the I/O controller **335**. The I/O controller **335** may be, for example, one or more buses or other wired or wireless connections, as are known in the art. The I/O controller **335** may have additional elements, which are omitted for simplicity, such as controllers, buffers (caches), drivers, repeaters, and receivers, to enable communications.

The I/O devices **340**, **345** may further include devices that communicate both inputs and outputs, for instance disk and tape storage, a network interface card (NIC) or modulator/demodulator (for accessing other files, devices, systems, or a network), a radio frequency (RF) or other transceiver, a telephonic interface, a bridge, a router, and the like.

The processor **305** is a hardware device for executing hardware instructions or software, particularly those stored in memory **310**. The processor **305** may be a custom made or commercially available processor, a central processing unit (CPU), an auxiliary processor among several processors associated with the computer system **300**, a semiconductor-based microprocessor (in the form of a microchip or chip set), a macroprocessor, or other device for executing instructions. The processor **305** includes a cache **370**, which may include, but is not limited to, an instruction cache to speed up executable instruction fetch, a data cache to speed up data fetch and store, and a translation lookaside buffer (TLB) used to speed up virtual-to-physical address translation for both executable instructions and data. The cache **370** may be organized as a hierarchy of more cache levels (L1, L2, etc.).

The memory **310** may include one or combinations of volatile memory elements (e.g., random access memory, RAM, such as DRAM, SRAM, SDRAM, etc.) and nonvolatile memory elements (e.g., ROM, erasable programmable read only memory (EPROM), electronically erasable programmable read only memory (EEPROM), programmable read only memory (PROM), tape, compact disc read only memory (CD-ROM), disk, diskette, cartridge, cassette or the like, etc.). Moreover, the memory **310** may incorporate electronic, magnetic, optical, or other types of storage media. Note that the memory **310** may have a distributed architecture, where various components are situated remote from one another but may be accessed by the processor **305**.

The instructions in memory **310** may include one or more separate programs, each of which comprises an ordered listing of executable instructions for implementing logical functions. In the example of FIG. **3**, the instructions in the memory **310** include a suitable operating system (OS) **311**. The operating system **311** essentially may control the execution of other computer programs and provides scheduling, input-output control, file and data management, memory management, and communication control and related services.

Additional data, including, for example, instructions for the processor **305** or other retrievable information, may be stored in storage **320**, which may be a storage device such as a hard disk drive or solid-state drive. The stored instructions in memory **310** or in storage **320** may include those enabling the processor to execute one or more aspects of the remediation systems **100** and methods of this disclosure.

The computer system **300** may further include a display controller **325** coupled to a display **330**. In some embodiments, the computer system **300** may further include a network interface **360** for coupling to a network **365**. The network **365** may be an IP-based network for communication between the computer system **300** and an external server, client and the like via a broadband connection. The network **365** transmits and receives data between the computer system **300** and external systems. In some embodiments, the network **365** may be a managed IP network administered by a service provider. The network **365** may be implemented in a wireless fashion, e.g., using wireless protocols and technologies, such as WiFi, WiMax, etc. The network **365** may also be a packet-switched network such as a local area network, wide area network, metropolitan area network, the Internet, or other similar type of network environment. The network **365** may be a fixed wireless network, a wireless local area network (LAN), a wireless wide area network (WAN) a personal area network (PAN), a virtual private network (VPN), intranet or other suitable network system and may include equipment for receiving and transmitting signals.

An embodiment of the present invention may be a system, a method, and/or a computer program product at any possible technical detail level of integration. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

The following definitions and abbreviations are to be used for the interpretation of the claims and the specification. As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having," "contains" or "containing," or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a composition, a mixture, process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but can include other elements not expressly listed or inherent to such composition, mixture, process, method, article, or apparatus.

As used herein, the articles "a" and "an" preceding an element or component are intended to be nonrestrictive regarding the number of instances (i.e., occurrences) of the element or component. Therefore, "a" or "an" should be read to include one or at least one, and the singular word form of the element or component also includes the plural unless the number is obviously meant to be singular.

As used herein, the terms "invention" or "present invention" are non-limiting terms and not intended to refer to any single aspect of the particular invention but encompass all possible aspects as described in the specification and the claims.

The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

What is claimed is:

1. A system comprising:

a plurality of virtual machines (VMs);

a shared storage pool (SSP) configured to store health information for the plurality of VMs;

a plurality of virtual input/output servers (VIO Ss) participating in the shared storage pool (SSP), wherein each VIOS is associated with a respective group of VMs of the plurality of VMs and is configured to receive health data for each VM of the respective group of VMs; and

a health information database associated with each VIOS of the plurality of VIOSs, the health information database configured to store a subset of the health data for each VM of the respective group of VMs,

wherein each VIOS is configured to transmit the health data for each VM of the respective group of VM to the SSP, and in parallel, store the subset of the health data in the health information database.

2. The system of claim **1**, wherein the subset of the health data is a copy of at least a portion of the health data stored in the SSP.

3. The system of claim **1**, wherein the health information database is a local database that resides on each VIOS.

4. The system of claim **1**, further comprising an orchestration node configured to monitor the VMs and manage the health data stored in the SSP.

5. The system of claim **4**, wherein each VIOS is configured to periodically receive the health data for each VM of the respective group of VMs, and in response transmit the received health data to the orchestration node and store the subset of the health data in the health information database.

6. The system of claim **4**, wherein the orchestration node is configured to query each VIOS and receive the subset of the health data in response to a failure of at least part of the SSP.

7. The system of claim **6**, wherein the orchestration node is configured to consolidate the health data received from each VIOS to reconstruct at least part of the health data that was stored in the SSP.

8. The system of claim **6**, wherein the orchestration node is configured to synchronize the plurality of VIOSs and the plurality of VMs based on the health data retrieved from the health information database.

9. A method of managing a shared storage environment, the method comprising:

monitoring the shared storage environment, the shared storage environment including a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP), wherein each VIOS is associated with a respective group of VMs of the plurality of VMs;

receiving health data for each VM of the respective group of VMs;

transmitting the health data for each VM of the respective group of VM to the SSP; and

in parallel, storing a subset of the health data for each VM of the respective group of VMs in a health information database, the health information database associated with each VIOS of the plurality of VIOSs.

10. The method of claim **9**, wherein the subset of the health data is a copy of at least a portion of the health data stored in the SSP.

11. The method of claim **9**, wherein the health information database is a local database that resides on each VIOS.

12. The method of claim **9**, further comprising managing the health data stored in the SSP by an orchestration node in communication with each VIOS, wherein each VIOS is configured to periodically receive the health data for each VM of the respective group of VMs, and in response transmit the received health data to the orchestration node and store the subset of the health data in the health information database.

13. The method of claim **12**, further comprising querying each VIOS and receiving the subset of the health data by the orchestration node in response to a failure of at least part of the SSP.

14. The method of claim **13**, further comprising consolidating, by the orchestration node, the health data received from each VIOS to reconstruct at least part of the health data that was stored in the SSP.

15. The method of claim **13**, further comprising synchronizing the plurality of VIOSs and the plurality of VMs by the orchestration node based on the health data retrieved from the health information database.

16. A computer program product comprising a non-transitory computer readable storage medium having program instructions embodied therewith, the program instructions executable by a processing system to perform a method including:

monitoring a shared storage environment, the shared storage environment including a plurality of virtual machines (VMs), a shared storage pool (SSP) configured to store health information for the plurality of VMs, and a plurality of virtual input/output servers (VIOSs) participating in the shared storage pool (SSP), wherein each VIOS is associated with a respective group of VMs of the plurality of VMs;

receiving health data for each VM of the respective group of VMs;

transmitting the health data for each VM of the respective group of VM to the SSP; and

in parallel, storing a subset of the health data for each VM of the respective group of VMs in a health information database, the health information database associated with each VIOS of the plurality of VIOSs.

17. The computer program product of claim **16**, wherein the health information database is a local database that resides on each VIOS.

18. The computer program product of claim **16**, wherein the method includes managing the health data stored in the SSP by an orchestration node in communication with each VIOS, wherein each VIOS is configured to periodically receive the health data for each VM of the respective group of VMs, and in response transmit the received health data to the orchestration node and store the subset of the health data in the health information database.

19. The computer program product of claim **18**, wherein the method includes querying each VIOS and receiving the subset of the health data by the orchestration node in response to a failure of at least part of the SSP, and consolidating the health data received from each VIOS to reconstruct at least part of the health data that was stored in the SSP.

20. The computer program product of claim **19**, wherein the method includes synchronizing the plurality of VIOSs and the plurality of VMs by the orchestration node based on the health data retrieved from the health information database.

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